Appendix A
Statement of Work
January 26, 2001
"University Research in Crystalline Silicon Photovoltaics"

1.0 Background

The mission of the U.S. Department of Energy (DOE) National Photovoltaics Program is to make photovoltaics (PV) a significant part of the domestic economy. This mission is described more completely in the Program's Five Year Research Plan (referenced in the Scope of Work below): *Photovoltaics—Energy for the New Millennium: The National Photovoltaics Program Plan for 2000—2004.* To meet the Program's challenge, the program uses a four-pronged strategy: First, we work in close concert with industry and other stakeholders to develop specific goals that serve as significant milestones on the path to achieving a PV technology competitive with other sources for generating electricity. The Program's Five Year Research Plan also contains the vision, strategies, and goals of the PV Industry Roadmap 2000---2020. Second, we use a vertically integrated development process---including basic research, applied research, engineering, product development, and manufacturing research---to bring technologies from the concept stage to commercial readiness. Third, all along this development process, we collaborate closely with R&D partners from government, industry, and universities. Finally, we validate the technology for specific applications by deploying prototype systems and documenting their performance.

Investment in basic scientific research is a long-term economic imperative for our Nation's technological strength. Science and technology have been, and will continue to be, the engine of U.S. economic growth. The purpose of this project is to nurture fundamental research directed to critical research issues in crystalline silicon photovoltaic technologies so they can compete with other energy technologies used in the world on a large scale.

Today's photovoltaic markets for terrestrial applications are based mostly on various forms of crystalline silicon. These technologies---the result of innovative research conducted 30 to 50 years ago---have enabled dozens of companies throughout the world to establish a billion-dollar industry marketing primarily to non-grid-connected applications. Viability in grid-connected applications, however, requires substantial cost reductions to achieve the long-term goal of generating inexpensive electricity from sunlight. Thin-film technologies, considered the next generation to crystalline-silicon technologies, came into being some 25 or more years ago as promising lower cost technologies. These technologies, based on non-silicon or amorphous silicon materials, are targeting the same long-term goal of generating inexpensive electricity from sunlight.

There is no reason to believe that fundamental research in crystalline silicon has gone as far as it can go. Fundamental and exploratory research is needed to see what can be done next to improve crystalline silicon photovoltaics further. Fundamental research can benefit silicon-based technologies, especially when focused on critical research issues identified jointly by industry and universities. This project will support the portfolio of activities in universities needed to nurture innovation and improve the cost effectiveness of crystalline silicon photovoltaics. It is expected to generate new knowledge with a purpose, not knowledge for knowledge's sake.

Guidance for the critical technical challenges facing crystalline silicon technologies comes from the *10th Workshop on Crystalline Silicon Solar Cell Materials and Processes* held in Copper Mountain, Colorado on August 14-16, 2000 (NREL/BK-520-28844). The workshop was attended by 85 scientists and engineers from 15 PV companies and 24 research institutions. In the wrap-up session of the workshop, a voting process was conducted for industry to rank the critical technical challenges they are facing or will face. The top five research topics are listed below in the Scope of Work. The workshop attendees also recommended the creation of cross-functional working groups, or research teams, having representatives from industry, academia, and government laboratories, to address the topics.

2.0 Objective

The objectives of this work effort are to:

A. Enable universities with strong crystalline silicon capabilities to explore critical research issues that can help the crystalline silicon PV industry make a significant contribution to our nation's energy supply and environment.
B. Support scientific research leading to crystalline silicon PV technologies with higher efficiency and lower cost for converting sunlight to electricity.

3.0 Scope of Work

Proposals submitted in response to this solicitation should target one or more of the five research topics identified at the *10th Workshop on Crystalline Silicon Solar Cell Materials and Processes*. They are:

- Develop replacement for, or vastly improve, screen printed metallization
- Develop low-cost, non-vacuum, hydrogenation techniques, and improve understanding of silicon nitride hydrogenation
- Develop methods of handling and processing thin wafers with high yield
- Develop new emitter technologies such as selective emitters, heterojunction emitters, etc.
- Discover how to neutralize bad regions and shunts.

Proposals may also be submitted in areas of fundamental scientific research in crystalline silicon photovoltaics not necessarily related to the five research topics listed above.

Depending on work efforts proposed, successful offerors may be directed after their awards to work closely with one or more of the following NREL teams.

A. The conductive paste working team

The current screen-printed metallization process limits cell performance compared to that attainable with vacuum deposited and lithographically defined metal. This team would work to improve the performance, and reduce the cost of cell metallization. Potential research topics include, but are not limited to:

- Increase understanding of how the metal-semiconductor contact works in the case of pastes with a goal to reduce contact resistance and silicon consumption
- Develop new inks with better conductive and rheological properties allowing thinner lines

- Develop a non-contact deposition technologies such as ink-jet deposition.

B. Hydrogenation team

Hydrogenation is now well established as a beneficial process in all multi-crystalline silicon cell designs. At this point there is no well-established method of hydrogenation that meets long range cost goals. The purpose of this working group is to research new low-cost methods of hydrogenation and to further fundamental understanding of how hydrogenation works. Possible topics for research include, but are not limited to:

- Improved understanding of the mechanisms behind Si_3N_4 hydrogenation
- Low-cost methods of Si_3N_4 deposition
- Fundamental research on the mechanisms of hydrogen passivation

C. Mechanical properties and yield team

There are many benefits to making cells thinner. Specifically, lower quality material can be utilized for the same cell performance, less silicon material is required, and ultimately higher performance is attainable. Experience has not been very encouraging in this regard, however, because of the increased breakage loss as cells get thinner. The goal of this team is to better understand the breakage mechanisms so that process and equipment designs can be tailored to thin wafers with high yield. Possible topics for research include, but are not limited to:

- Breakage mechanisms
- Growth process impacts
- Wafer cutting impacts
- Effect of grown-in stress
- Measurement of grown-in stress
- Analysis and detection of microcracks

D. Selective emitters team

Selective emitters can provide significant cell improvements, but to date no such process is in widespread production (with the exception of the laser-buried-contact cell.) This team will research new approaches to selective emitters with the goal of finding one or more processes that cost-effectively increase efficiency. Possible topics for research include, but are not limited to:

- Alloy emitters
- Heterojunction emitters
- Selective etching
- Self-aligned two-step processes

E. Low lifetime region team

Grown-in regions of low lifetime in cast multi-crystalline silicon still result in lower performance from these wafers than in single crystal silicon. Much progress has been made over the last decade in understanding the nature of these regions, such as the fact that the low lifetime comes from precipitates; however, to date no cost-effective method of completely eliminating them has been developed. The goal of this team is to do just that. This will require a close working relationship between crystal growers and cell manufacturers. Possible topics for research include, but are not limited to:

- Identification and understanding of the chemical state of precipitates in low-lifetime regions
- Diagnostic methods for detecting and characterizing precipitates
- In-line testing for detection of precipitates
- Innovative methods for eliminating precipitates
- Innovative methods for passivating precipitates

4.0 Reporting Requirements

The milestones and deliverables for the R&D to allow for appropriate evaluation of progress and reporting requirements are listed below:

Quarterly Technical Status Reports
Annual Technical Progress Reports
Final Technical Report
Cost Plan
Deliverables

5.0 Addresses

One copy of each deliverable shall be sent to the following two (2) people:

NREL
Attn: Technical Monitor
1617 Cole Boulevard
Golden, CO 80401

NREL
Attn: Liz Surek, MS 2713
Contract Administrator
1617 Cole Boulevard
Golden, CO 80401